# Black carbon instrument intercomparison by source type

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# Different BC measurements are used throughout its atmospheric lifetime

Remote sites and vertical profiles in the atmosphere have been mostly equivalent black carbon or refractory black carbon

Multiple measurement methodologies?
No standard calibration material?

Application of EC fraction to PM emission factors? Is BC = EC?

Long term monitoring across the US is in terms of elemental carbon (EC) through the IMPROVE and Chemical Speciation Trends Network

EPA National Emissions Inventory is based on measurements of elemental carbon (EC) taken at the source

# Our approach to sort out some of these measurement issues:

Use multiple measurement methods on multiple sources to quantify differences between measures and identify suitable operating parameters.

**Filter based absorption (EBC = Equivalent BC):**

Aethalometer (AE22, AE33, AE51, AE52)



**In situ absorption (BC):**

PASS-3 – Photoacoustic Soot Spectrometer

**Laser induced incandescence (rBC= Refractory BC):**

SP2 – Single Particle Soot Photometer


All BC measures are compared to a thermal optical measurement of elemental carbon (EC): NIOSH 5040

# How we deal with calibration:

All measures are made on a mass basis

## Filter based absorption (EBC): Aethalometer (AE22, AE33, AE51, AE52)

AE22 & AE51/52 - we use the manufacturer's MAC – 16.6 $m^2/g$ (at 880 nm)

AE33 – we use the manufacturer's MAC – 12.2 $m^2/g$ (at 880 nm) (Drinovec et al. 2015)

Derived from thermal measurement of EC with OC chemically extracted

## In situ absorption (BC): PASS-3

MAC from Bond & Bergstrom (2006) 5.28 $m^2/g$ @ 781 nm derived from best estimate from multiple measurements and methods

## Laser induced incandescence (rBC): SP2

Aquadag mass calibration corrected to 'ambient BC calibration' (Baumgartner et al. 2013)

Fullerene soot mass calibration 'surrogate for ambient BC'

## Thermal Optical (EC): NIOSH 5040

Thermal Optical Transmission calibrated with sucrose

# Assess BC emissions from fossil fuel sources

Pilot scale coal power pant

Stationary diesel genset


BC instrument bench

# Assess BC emissions from biomass burning

Ground-Based particle characterization immediately down wind of the source and repeated in the lab for comparison

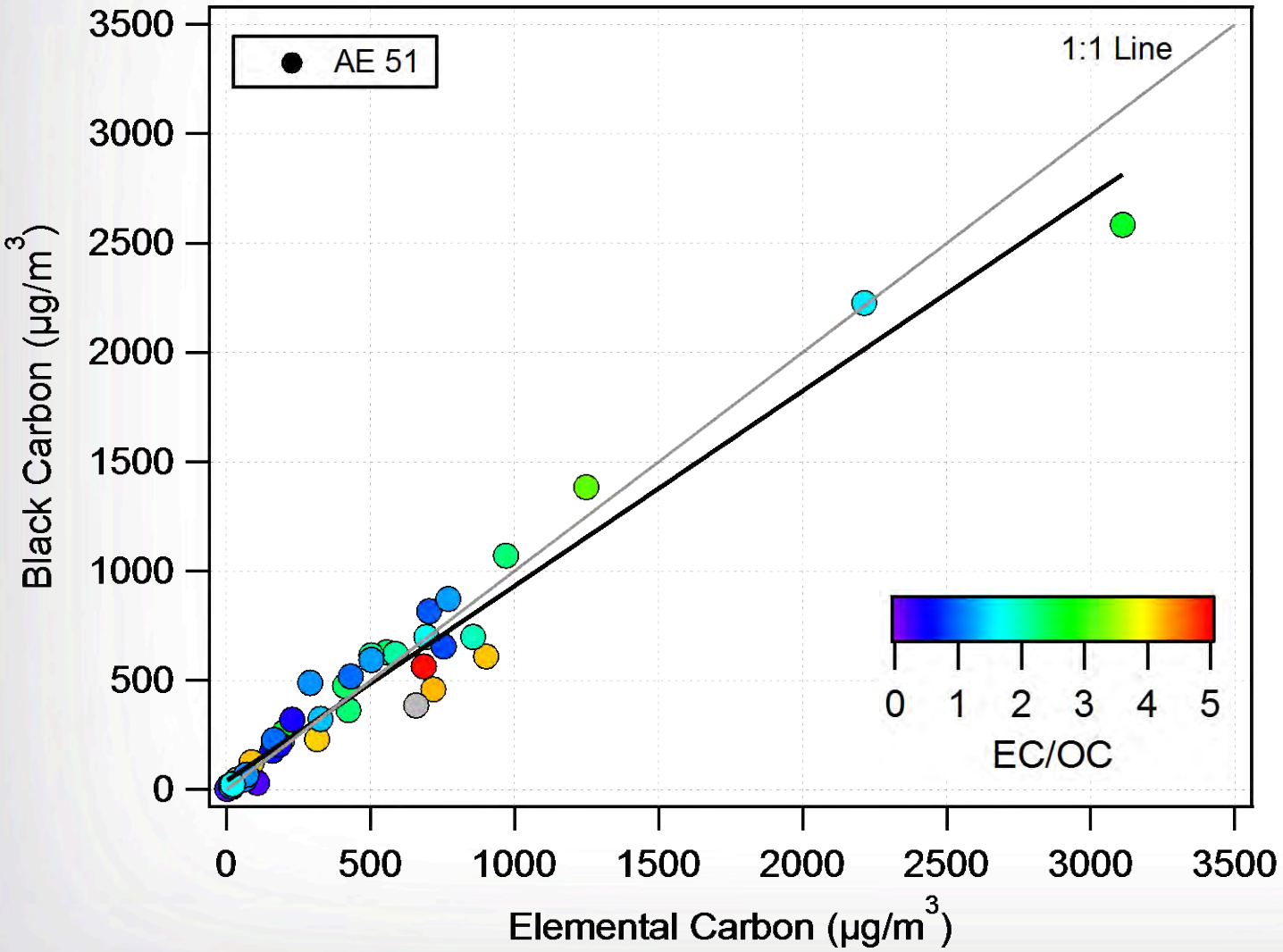
| Biomass Type | Fire Type | Location |
|---|---|---|
| Temperate forest | Prescribed fire | Ft. Jackson, SC |
| Temperate forest | Prescribed fire | Eglin AFB, FL |
| Grass and forbs | Prescribed fire | Eglin AFB, FL |
| Wheat straw, Kentucky blue grass | Agricultural | Nez Perce, ID |
| Wheat straw | Agricultural | Walla Walla, WA |

# Assess BC emissions from cookstoves

**Measured EC, rBC, BC and EBC on a variety of different cookstoves with a red oak fuel (dry and wet) using the water boiling test**

Jetter et al. 2012

# How do these measures compare for cookstove emissions measured in the lab?

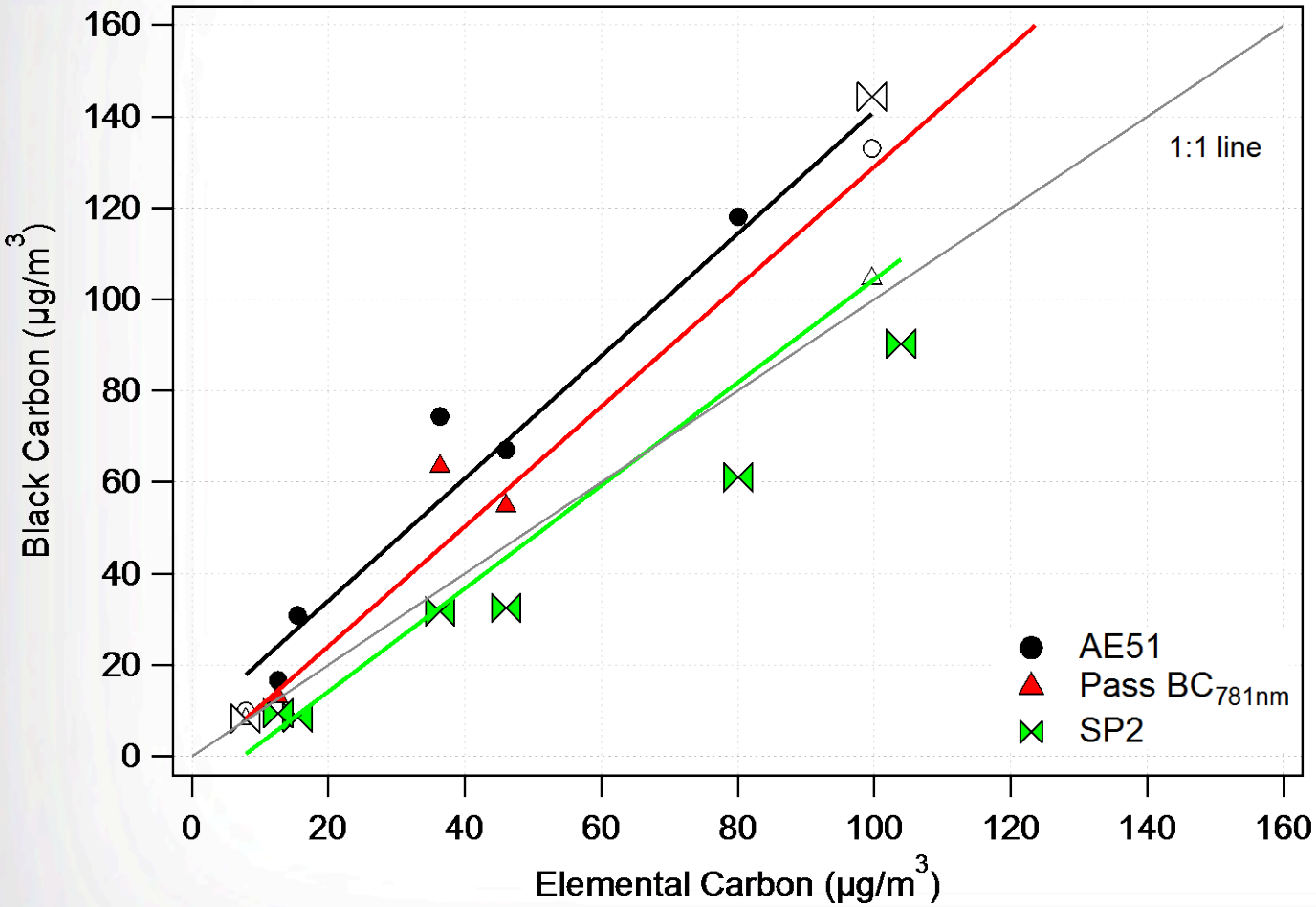



Improved stoves burning mostly red oak, some charcoal, and some kerosene

$$BC = m \times EC + b$$

| Instrument | m | b | $r^2$ | BC/EC |
|---|---|---|---|---|
| AE-51 | 0.89 | 40.7 | 0.96 | 1.07±0.32 |

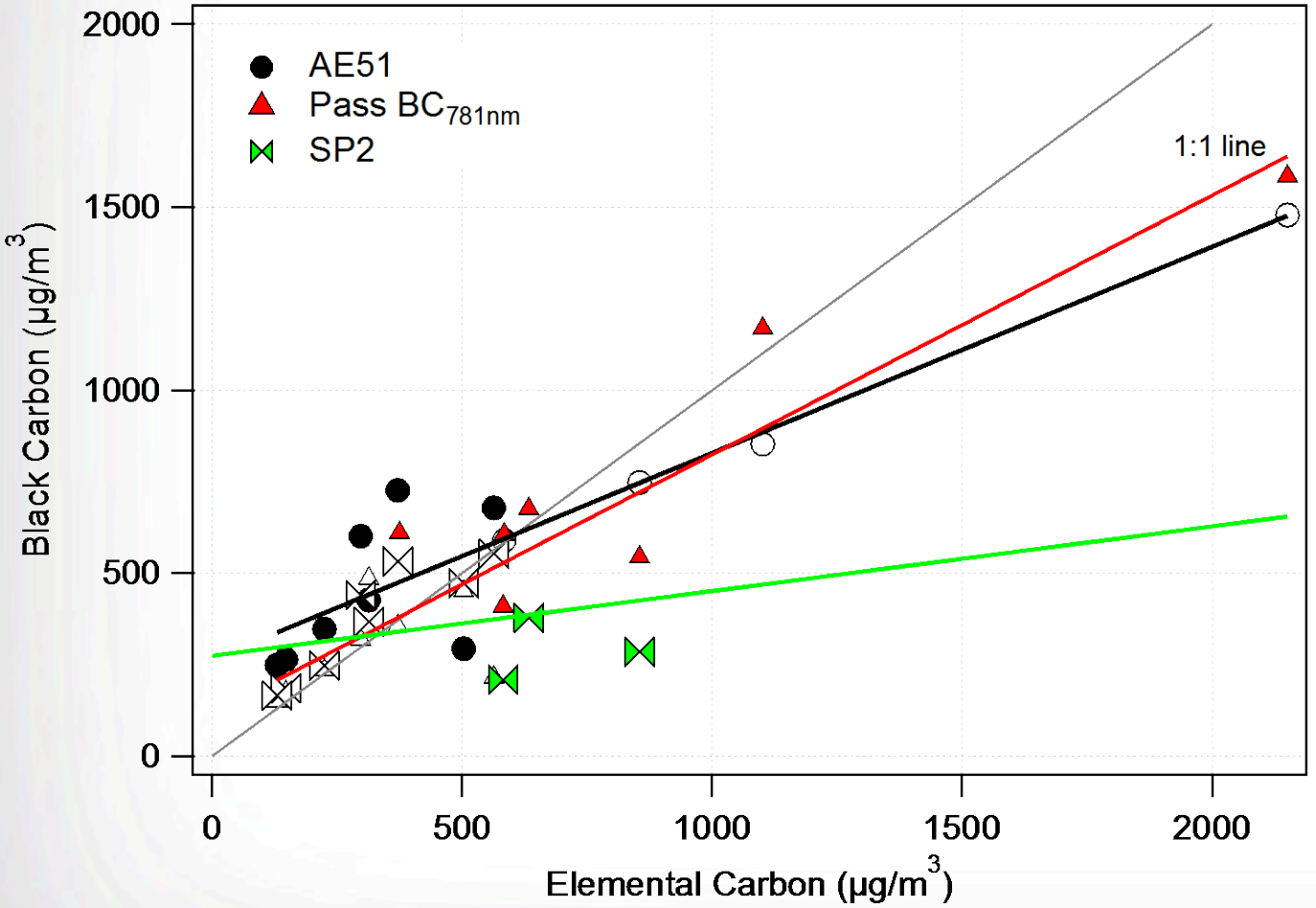
# How do these measures compare for open biomass burning in field?




Open symbols = grasses
agricultural residues
Filled symbols = forests

| Instrument | m | b | $r^2$ | BC/EC |
|---|---|---|---|---|
| AE-51 | 1.34 | 7.27 | 0.96 | 1.56±0.33 |
| PASS 781 nm | 1.31 | -2.01 | 0.97 | 1.24±0.28 |
| SP2 | 1.13 | -8.36 | 0.84 | 0.88±0.27 |

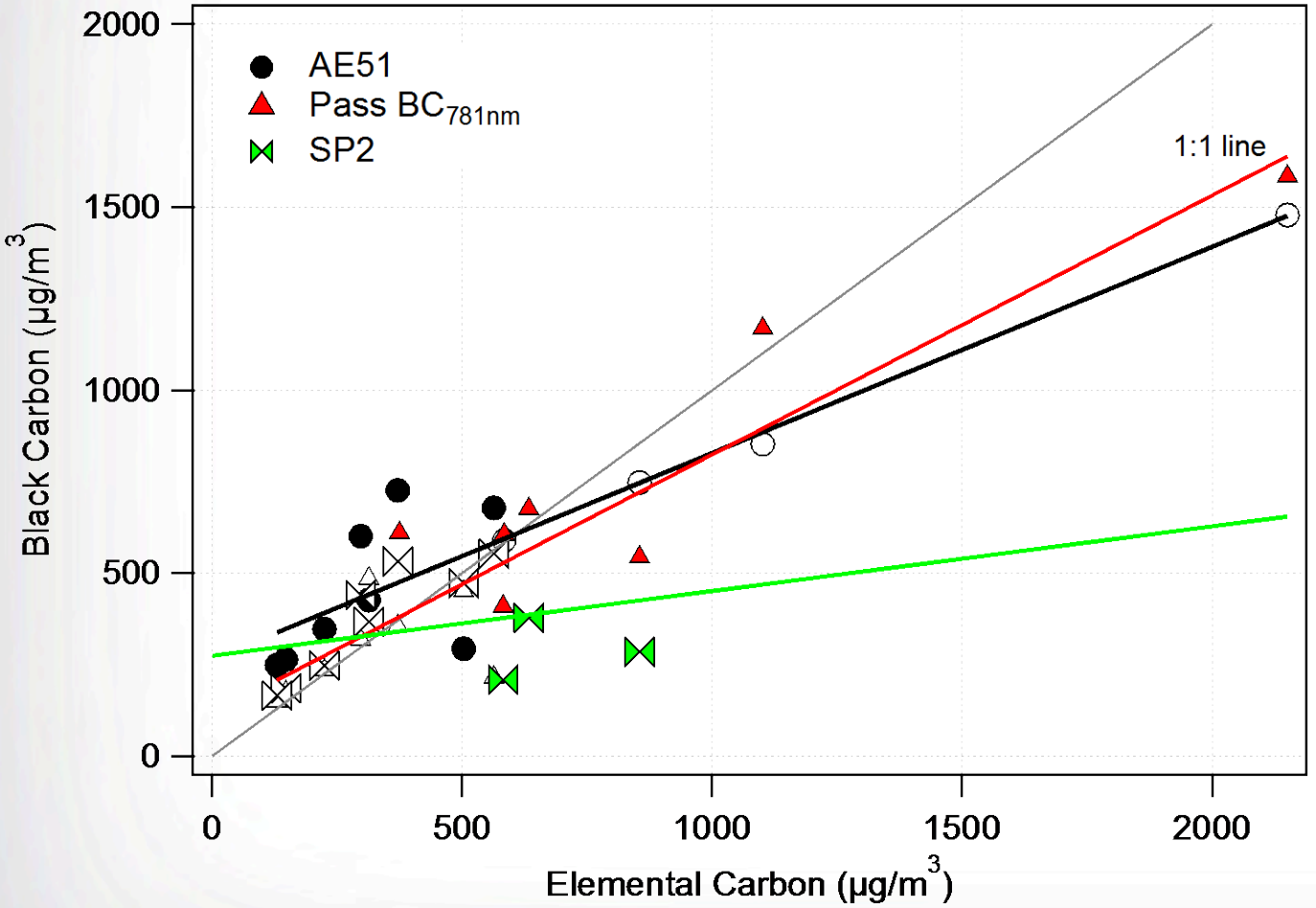
# How do these measures compare for open biomass burning including lab simulations?




Open symbols = grasses
agricultural residues
Filled symbols = forests

| Instrument | m | b | $r^2$ | BC/EC |
|---|---|---|---|---|
| AE-51 | 0.86 | 264.7 | 0.86 | 1.31±0.53 |
| PASS 781 nm | 0.71 | 115.5 | 0.85 | 1.00±0.32 |
| SP2 | 0.18 | 274.6 | 0.08 | 0.99±0.40 |

# How do these measures compare for open biomass burning including lab simulations?

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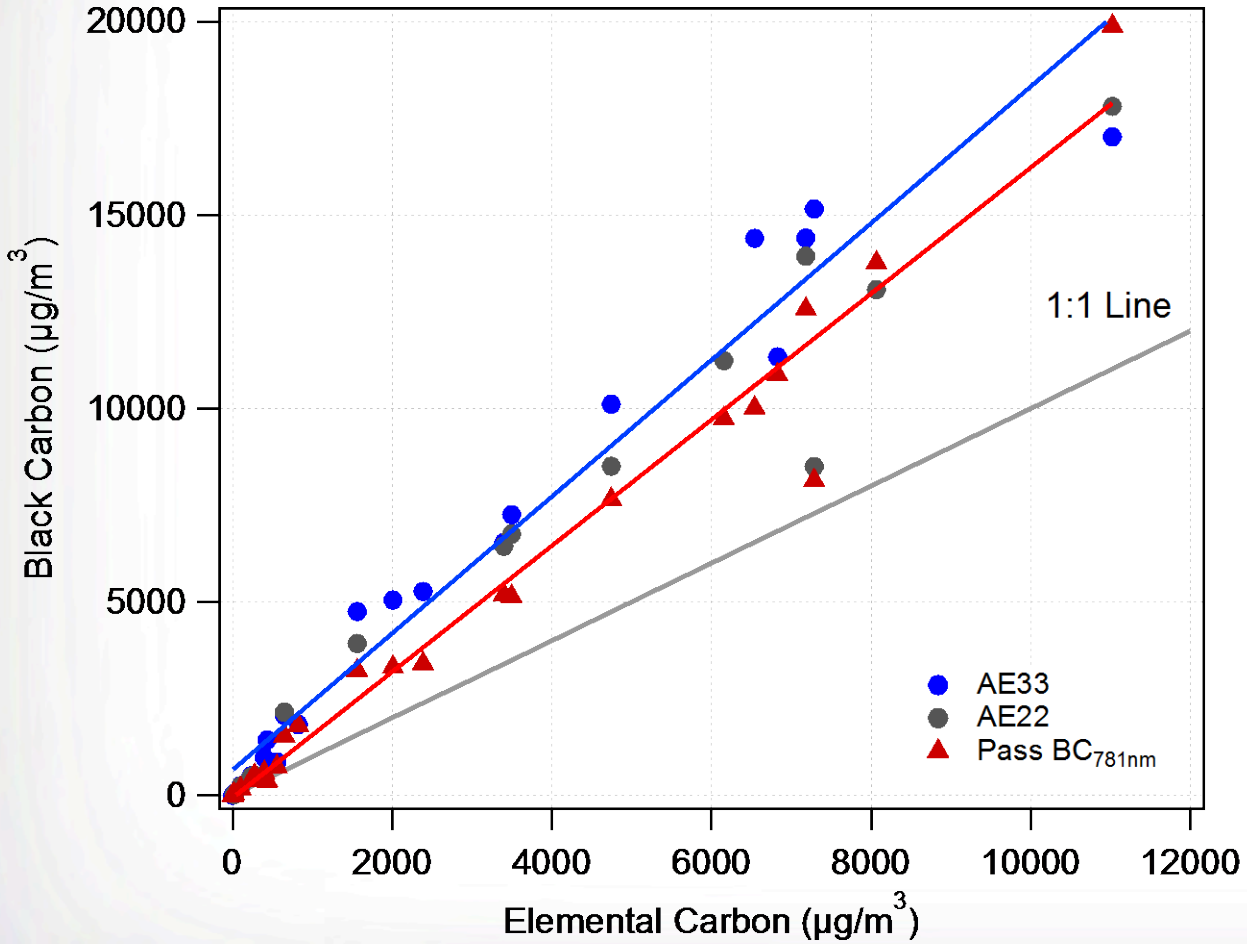
| SP2 | 0.18 | 274.6 | 0.08 | 0.99±0.40 |

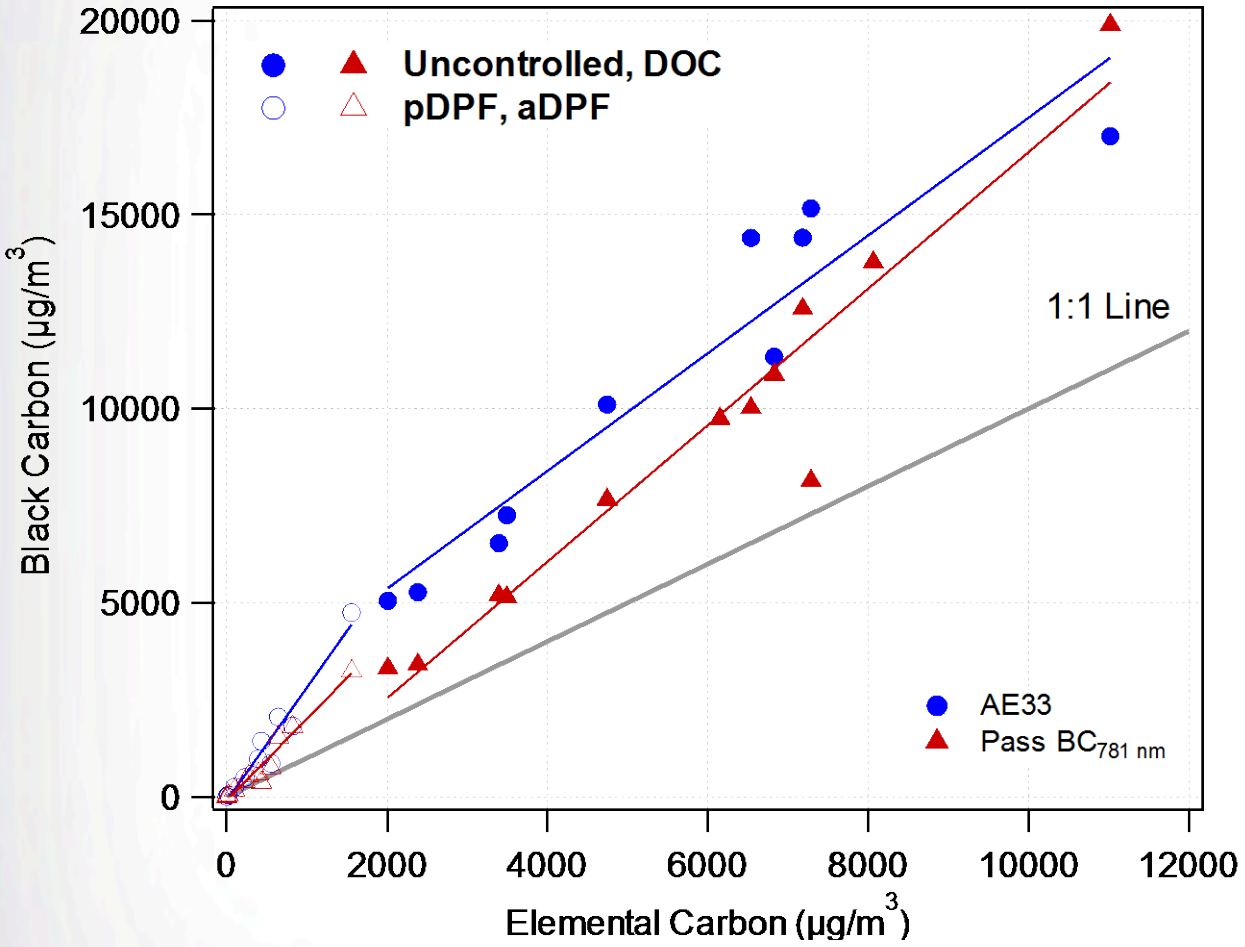
# How do these measures compare for diesel exhaust?

Stationary diesel gensets (230 kW, 400 kW, 600 kW) with and without control technology




| Instrument | m | b | $r^2$ | BC/EC |
|---|---|---|---|---|
| AE-33 | 1.77 | 662.5 | 0.96 | 2.27±0.50 |
| AE-22 | 1.57 | 617.5 | 0.95 | 1.92±0.58 |
| PASS 781 nm | 1.63 | -66.0 | 0.98 | 1.65±0.33 |

# A clear difference in the BC – EC relationship with control technology




**Control technology used:**

**pDPF = Passive diesel particulate filter**

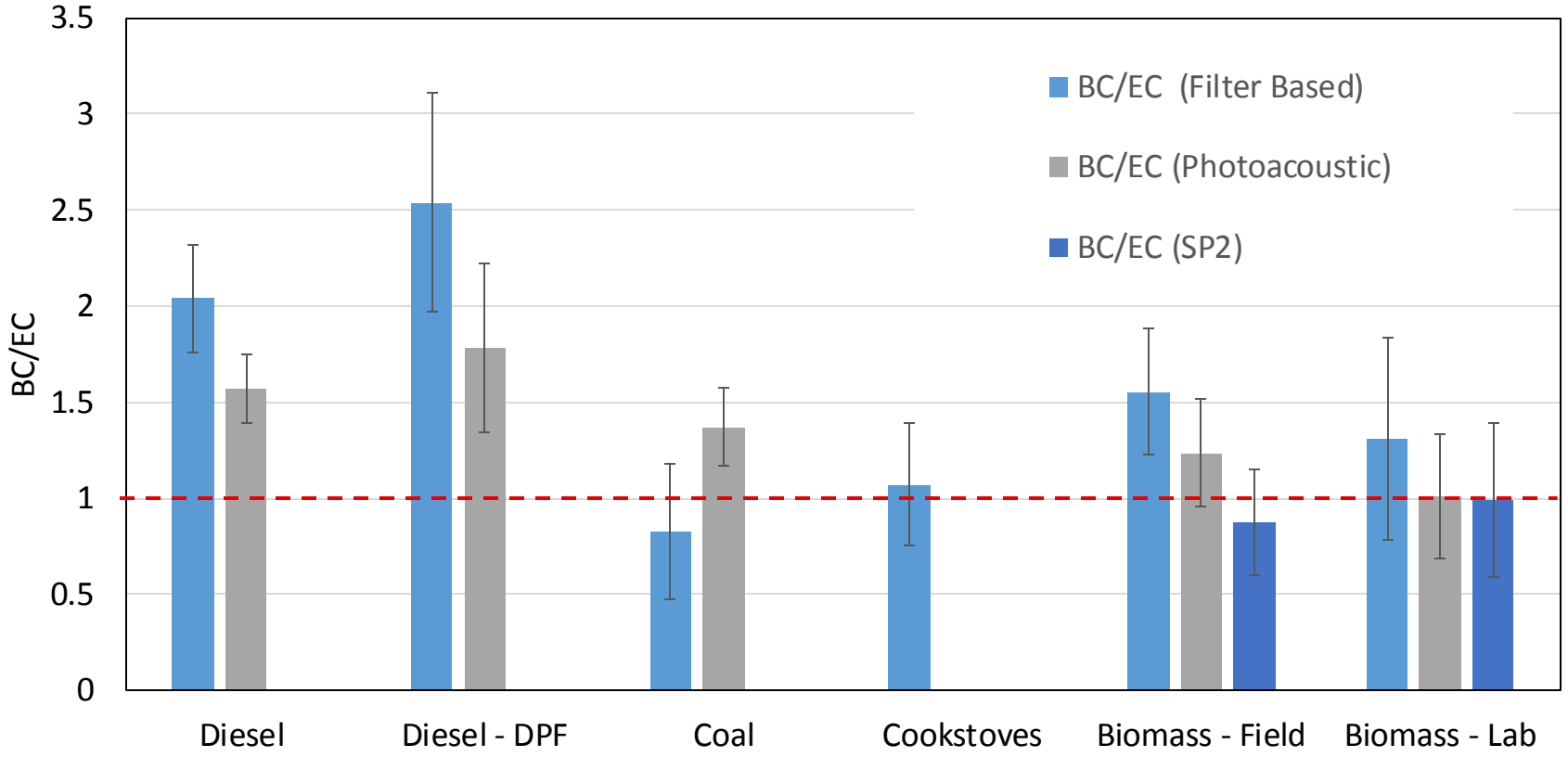
**aDPF = Active diesel particulate filter**

**DOC = Diesel oxidative catalyst**

| | Instrument | m | b | $r^2$ | BC/EC |
|---|---|---|---|---|---|
| Uncontrolled /DOC | AE-33 | 1.52 | 2333.2 | 0.90 | 2.04±0.28 |
| | PASS 781 nm | 1.76 | -978.7 | 0.93 | 1.57±0.18 |
| pDPF/aDPF | AE-33 | 2.92 | -106.7 | 0.95 | 2.54±0.57 |
| | PASS 781 nm | 2.104 | -94.3 | 0.95 | 1.78±0.44 |

# Mean BC/EC by source, by method

Diesel exhaust has the highest ratio!




Also, observed BC/EC ~ 2 for flame soot (Yelverton et al. 2014) and ~ 1.5 for a modern heavy duty diesel (Robinson et al. 2015)

Filter based BC > Photoacoustic BC

# What are the important characteristics determining optical properties?

## Factors impacting absorption:

Refractive index

Morphology

Coating

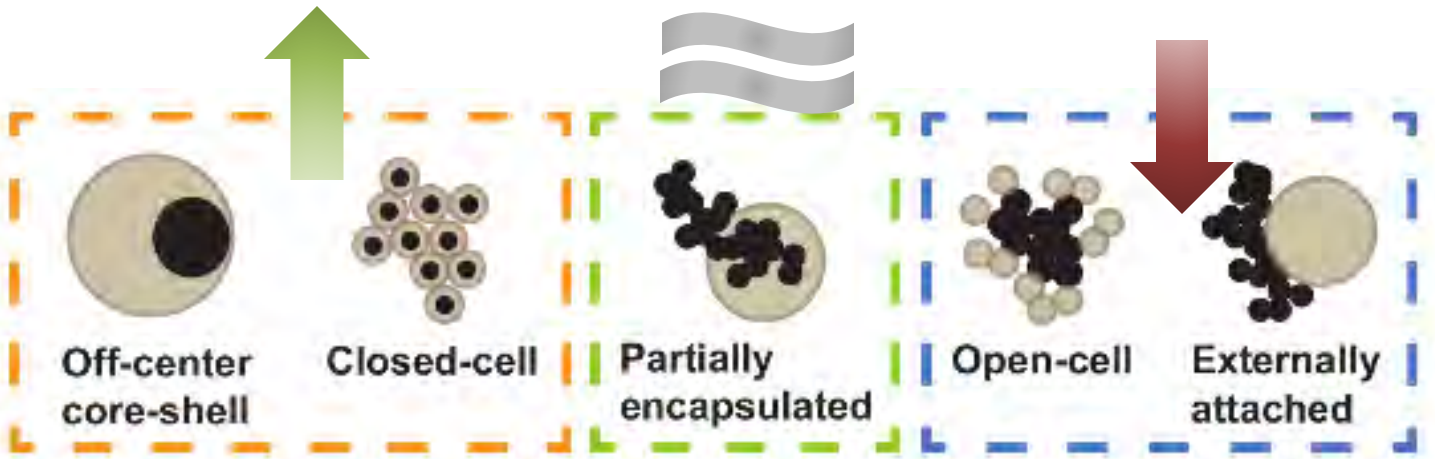



Image from: He, Liou, Takano, Zhang, Zamora, Yang, Li, Leung, Variation of radiative properties during black carbon aging: theoretical and experimental intercomparison, Atmos. Chem. Phys. Discuss. 15, 19835-19872, 2015

# Conclusions

For most sources BC is +/- 50% EC

rBC is impractical for BC measurement under source sampling conditions

Biomass sources tended to have better agreement between EBC, BC and EC

Cookstoves cover a range of EC/OC values but still show the highest level of agreement

Diesel exhaust showed a consistently higher EBC and BC compared to EC

Questions remain as to what causes these differences

## Acknowledgements:

**US EPA**: Bill Mitchell, Bill Squire, Rob Elleman, Dave Nash

**US Forest Service**: Shawn Urbanski, Susan O'Neill

**Arcadis:** Carl Singer, Daniel Janek